While the shaft sealing apparatus 300 has been described in the above as comprising a center shaft 340 rotatable around its own axis with respect to the sleeve shaft 330, the center shaft 340 may be replaced by a center shaft axially movable along its own axis with respect to said sleeve shaft 330 according to the present invention.

The shaft sealing apparatus 300 further comprises a first sealing unit 350 received in the annular ledge 330d of the sleeve shaft 330 and fixedly supported by the sleeve shaft 330. The first sealing unit 350 includes a retaining member 351 in the form of an annular ring shape and fixedly supported by the sleeve shaft 330, and a plurality of sealing rings 153 securely retained by the retaining member 351 of the first sealing unit 350 to be held in axial alignment with each other. Each of the sealing rings 153 of the first sealing unit 350 is in the form of an annular ring shape and intervenes between the center shaft 340 and the retaining member 351 of the first sealing unit 350 to hermetically seal the gap between the center shaft 340 and the retaining member 351 of the first sealing unit 350. The sealing rings 153 of the first sealing unit 350 are held in contact with each other.

The retaining member 351 of the first sealing unit 350 has a first axial end 351a extending in the vacuum chamber 311 of the vacuum casing 310, a second axial end 351b held in contact with the annular ledge 330d of the sleeve shaft 330, and an inner cylindrical surface 351c larger in diameter than the outer cylindrical surface 340b of the center shaft 340. The inner cylindrical surface 351c of the retaining member 351 is formed with an annular ledge 351d connected with the first axial end 351a of the retaining member 351.

Each of the sealing rings 153 of the first sealing unit 350 includes an annular resilient member 154 formed with an annular groove 154a, and an annular spring member 155 received in the annular groove 154a of the annular resilient member 154 and retained by the annular resilient member 154 as shown in FIG. 2. The annular resilient member 154 of the sealing ring 153 has a peripheral portion 154b securely retained by the annular ledge 351d of the retaining member 351, and a sealing lip 154c integrally formed with the peripheral portion 154b of the annular resilient member 154 and radially inwardly extending from the peripheral portion 154b of the annular resilient member 154 to be held in contact with the outer cylindrical surface 340b of the center shaft 340. The sealing lip 154c of the annular resilient member 154 is made of a synthetic resin constituted by an ultra high molecular weight compound.

The annular resilient member 154 of the sealing ring 153 may have a reinforcing portion 154d covered by a rubber and intervening between the peripheral

portion 154b of the annular resilient member 154 and the sealing lip 154c of the annular resilient member 154 to have the resilient member 154 reinforced with the annular reinforcing portion 154d. The reinforcing portion 154d of the annular resilient member 154 is made of a metal plate in the form of an annular ring shape and is of an L-shaped cross-section taken on the plane perpendicular to the center axis passing therethrough.

The annular spring member 155 of the sealing ring 153 is operative to impart a force to the sealing lip 154c of the annular resilient member 154 to ensure that the sealing lip 154c of the annular resilient member 154 is held in tight contact with the outer cylindrical surface 340b of the center shaft 340. The annular spring member 155 of the sealing ring 153 is made of a metal wire in the form of a helical shape and is of a circular cross-section taken on the plane perpendicular to the center axis passing therethrough. The annular spring member 155 thus constructed is generally called "garter spring".

In the third embodiment of the shaft sealing apparatus according to the present invention, the outer cylindrical surface 340b of the center shaft 340 is smaller in surface roughness Ra than 0.1 μm and larger in Vickers hardness Hv than 650.

The sealing lip 154c of the annular resilient member 154 may be held in contact with the outer cylindrical surface 340b of the center shaft 340 with a vacuum grease constituted by a lubricant containing fluorine. The first sealing unit 350 may include a plurality of sealing rings 153 each having a sealing lip 154c coated with the vacuum grease. The first sealing unit 350 may also include a plurality of sealing rings 153 each having a sealing lip 154c to have the sealing lips 154c collectively form an annular groove filled with the vacuum grease. The first sealing unit 350 may also include a plurality of sealing rings 153 each having a sealing lip 154c and a subsidiary sealing lip held in contact with the outer cylindrical surface 340b of the center shaft 340 to have the sealing lip 154c and the subsidiary sealing lip collectively form an annular groove filled with the vacuum grease.

The shaft sealing apparatus 300 further comprises a first bearing 359 intervening between the center shaft 340 and the sleeve shaft 330 to have the center shaft 340 movably supported by the sleeve shaft 330 through the first bearing 359. The first bearing 359 is located between the sealing ring 153 of the first sealing unit 350 and the second axial end of the center shaft 340 in axially spaced-apart relationship with the sealing ring 153 of the first sealing unit 350.

The shaft sealing apparatus 300 further comprises first driving means constituted by an electric motor, not shown. The electric motor is operatively connected with the second axial end of the center shaft 340 to rotate the center shaft

340 around its own axis. While the driving means has been described in the above as being constituted by an electric motor operatively connected with the second axial end of the center shaft 340, the electric motor may be replaced by a reduction gear unit and an electric motor operatively connected with the second axial end of the center shaft 340 through the reduction gear unit.

The shaft sealing apparatus 300 further comprises a second sealing unit 360 received in the annular ledge 320d of the shaft housing 320 and fixedly supported by the shaft housing 320. The second sealing unit 360 includes a retaining member 361 in the form of an annular ring shape and fixedly supported by the shaft housing 320, and a plurality of sealing rings 163 securely retained by the retaining member 361 of the second sealing unit 360 to be held in axial alignment with each other. Each of the sealing rings 163 of the second sealing unit 360 is in the form of an annular ring shape and intervenes between the sleeve shaft 330 and the retaining member 361 of the second sealing unit 360 to hermetically seal the gap between the sleeve shaft 330 and the retaining member 361 of the second sealing unit 360. The sealing rings 163 of the second sealing unit 360 are held in contact with each other.

The retaining member 361 of the second sealing unit 360 has a first axial end 361a extending in the vacuum chamber 311 of the vacuum casing 310, a second axial end 361b held in contact with the annular ledge 320d of the shaft housing 320, and an inner cylindrical surface 361c larger in diameter than the outer cylindrical surface 351d of the sleeve shaft 330. The inner cylindrical surface 361c of the retaining member 361 is formed with an annular ledge 361d connected with the first axial end 361a of the retaining member 361.

Each of the sealing ring 163 of the second sealing unit 360 includes an annular resilient member 164 formed with an annular groove 164a, and an annular spring member 165 received in the annular groove 164a of the annular resilient member 164 and retained by the annular resilient member 164 as shown in FIG. 2. The annular resilient member 164 of the sealing ring 163 has a peripheral portion 164b securely retained by the annular ledge 361d of the retaining member 361, and a sealing lip 164c integrally formed with the peripheral portion 164b of the annular resilient member 164 and radially inwardly extending from the peripheral portion 164b of the annular resilient member 164 to be held in contact with the outer cylindrical surface 330b of the sleeve shaft 330. The sealing lip 164c of the annular resilient member 164 is made of a synthetic resin constituted by an ultra high molecular weight compound.

The annular resilient member 164 of the sealing ring 163 may have a reinforcing portion 164d covered by a rubber and intervening between the peripheral